

ERDC/CERL TR-05-29

Construction Engineering
Research Laboratory



**US Army Corps
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Engineer Research and
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Effects of Forests on Blast Noise

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October 2005

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Final Report

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Prepared for U.S. Army Environmental Center
 Aberdeen Proving Ground, MD 21010-5401

Under Work Unit #H1LH7C

ABSTRACT: Low-frequency impulsive noise, characteristic of demolitions, artillery, and armor, is difficult to mitigate. In 2001, ERDC-CERL researchers were tasked to study the potential attenuation caused by a forest. After a thorough review of published work, it was determined that an experiment was necessary. This took place in July 2002 at the Lone Star Army Ammunition Plant in Texarkana, Texas. This report presents the data analysis and draws conclusions about the effectiveness of a forest stand on noise mitigation. Additionally, some predictive modeling has been performed, and those results also are included.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32)$	degrees Celsius
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32) + 273.15$	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

* *Système International d'Unités* ("International System of Measurement"), commonly known as the "metric system."

Preface

This study was conducted for the U.S. Army Environmental Center (USAEC) under MIPR3L48R00122/PO, “Effects of forest on blast noise levels.” The technical monitor was Mr. Tom Vorac, SFIM-AEC-TSR.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigators were Michelle E. Swearingen, Michael J. White, and Larry L. Pater. The technical editor was Gloria J. Wienke, Information Technology Laboratory. Alan B. Anderson is Chief, CEERD-CN-N, and L. Michael Golish is Acting Chief, CEERD-CN. The associated Technical Director was Dr. William J. Severinghaus. The Acting Director of CERL is Dr. Ilker Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

Received sound level is profoundly affected by propagation conditions between the sound source and receiver. This effect is particularly important for blast noise because the sound sources are powerful, and thus the sound can be loud at considerable distances. The effect of a forest on propagation of blast noise generated by large guns and explosions is currently not well understood. Theoretically, the forest might affect noise propagation in several different ways, including scattering and absorption by trunks, branches, and leaves; by absorption by the porous ground conditions caused by detritus in the forest; and by the effects of the forest on microclimate values of wind and temperature. No definitive experimental data could be found regarding whether low-frequency (30 to 80 Hertz [Hz]) blast noise from military activities will be scattered or absorbed by forest vegetation, and contradicting anecdotal evidence exists. Although the ground surface impedance within a forest is known to be absorptive at higher frequencies, there is a lack of measured data at low frequencies.

This report contains data on the measured blast wave signatures both inside and outside of a forest, the results of analytical modeling, and a discussion of implications for blast noise mitigation. This information will provide guidance for forestry and training managers regarding the efficacy of one particular type of forest for attenuation of blast noise levels in the surrounding community.

Objectives

The objectives of the research were to determine whether a forest can mitigate military blast noise and, if so, to gain an understanding of the effects to allow the Army to wisely manage its training facilities.

Approach

This project has leveraged funding from the Army Materiel Command (AMC), U.S. Army Environmental Center (USAEC), and the Corps of Engineers (COE) over the

past few years to accomplish the objectives and to meet the needs of these organizations. Following is a brief summary of the project to date.

During FY01 a thorough review of existing scientific literature on the effect of forests on low-frequency noise propagation was conducted. References were assessed for scientific accuracy and relevancy (Albert 2004). During FY01 an existing data set also was investigated, the so-called Norway trials, for low-frequency blast noise propagation through forests (Albert, et al. 2004). An extensive series of test measurements involving forest effects on blast wave propagation was conducted in Norway during 1994 through 1996, but the data had not been analyzed in a way to answer questions of current interest in this project. Researchers obtained access to and examined these data sets for forest effects, in particular a short-range measurement series (100-m to 1400-m ranges) conducted in a forest and in an open field, using explosions of an appropriate size for the current purposes, which offered possible potential for direct comparison to determine forest effects. Both the literature and the Norway trials data are generally useful but not definitive for purposes of this project.

During FY02 field measurements were made to obtain specific information regarding the effect of forests on blast noise propagation. A detailed test plan was developed and submitted to the research sponsors. The experiment was conducted at Lone Star Army Ammunition Plant (LSAAP), located in Texarkana, Texas, in the northeastern part of the state. The experiment was designed to provide direct comparison between blast noise propagation, in particular sound attenuation, in open fields and in forests.

Data analysis was conducted during FY03 and FY04 under AMC, USAEC, and COE funding to determine the changes in waveform shape, frequency content, and peak amplitude levels caused by the forest.

Scope

The results presented in this report are tailored to the forest surrounding LSAAP, and are applicable to other forests only in a general fashion. One important thing to keep in mind when examining the model results is that the vertical sound speed profile was not adjusted when the number of trees in the model was cut in half. The density of the trees probably will affect the vertical sound speed profile and, therefore, the sound propagation, particularly in the low-frequency range (10 to 50 Hz), which is of considerable interest for demolitions, armor, and artillery. Unfortunately, this issue could not be addressed during FY04.

This project concentrates on a particular type of forest, namely stands typical of the southern United States that are composed principally of evergreen species. The results of this project are valid for this type of forest, and may be indicative only for other types of forest, for example deciduous forests. The experimental portions of this project used explosives as the noise source, which are the typical noise source for demolition activity. However, the results and conclusions of this project could be extended to training activity involving large guns such as armor and artillery.

Mode of Technology Transfer

This report will be furnished directly to the U.S. Army Environmental Center for use and distribution. It also will be provided to the Operational Noise Program of the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), the Army technical transfer agent for and primary user of military blast noise technology, and to other known users, particularly the Assistant Chief of Staff, Installation Management; forestry managers at AMC and other major commands; and Installation Management Agency (IMA) installations.

This report will be made accessible through the World Wide Web (WWW) at URL: <http://www.cecer.army.mil>

2 Methods

The U.S. Army Engineer Research and Development Center (ERDC) performed a series of experimental measurements at LSAAP during July 24 and 25, 2002, to determine the sound attenuation effect of a mature forest on an explosively generated sound wave. This report describes the data analysis and preliminary predictive modeling. It also provides preliminary recommendations regarding forest management for noise mitigation. Significant caveats apply to the modeled results.

As part of its routine operation, LSAAP disposes of ordnance and munitions by explosive detonation. Disposal takes place within the new demolition ground (NDG). Conditions permitting, up to four series of detonations are completed each working day between 0700 and 1700 local time. A series consists of linear placement of 12 holes with a diameter of 0.46 m (18 in.) drilled into the ground approximately 2.7 m (9 ft) deep with a 30.5 m (100 ft) separation between holes. Munitions up to 45 kg (100 lb) net explosive weight are loaded into each hole, packed with a detonating agent, electrically fused, and connected by wire to the demolition shack approximately 366 m (1200 ft) from the outer edge of the NDG. The series of explosions is fired sequentially along the line, with approximately a 60-second delay between explosions. As a noise control practice, the A-weighted peak maximum sound pressure level ("fast" time weighting) is recorded with a sound level meter placed several feet from the demolition shack on a 6.1-m (20-ft) pole, and by a sound level meter on a tripod near the pole. Occasional complaints (due to noise, house shaking, etc.) are received from residents living nearby east of the installation boundary.

Forest tracts surrounding the NDG provide a visual and possible auditory screen between the detonation operations at the NDG and points beyond the installation boundary. The tracts in the immediate vicinity of the demolition area serve to reduce wind flow within the NDG, and dirt particles thrown by the blast are not wind-blown outside the NDG. The inner tracts are deemed by LSAAP to be essential for dust containment and safety, and they are off limits for timber harvesting. Were it not for the supposed noise mitigation benefit afforded by the forest tracts near the boundary, some outer tracts might be harvested and timber sold. At the time of this writing, the outer tracts are declared by LSAAP to be unavailable for timber harvest. In order to minimize noise complaints without affecting existing operations, any additional noise mitigation benefit by the outer tracts suffices to prevent timber harvesting. The question to answer is: do these tracts provide any additional noise mitigation benefit?

An experimental measurement was designed to estimate the noise mitigation benefit of the extant trees, considering a side-by-side comparison of attenuation in the forest to attenuation in the open field. The experimental design includes short propagation paths over comparable distances (approximately 300 m [985 ft]) in the open field and in the forest. The experiment also included four, long-range data collection sites (approximately 1400 m [4593 ft]). However, most of the data from these sites are unusable due to equipment malfunction. Therefore, data from the remote sites are not examined in this report.

Explosive charges of Composition C-4 were used as the sound source. The use of C-4 provided a high-pressure, broadband, compact, omnidirectional source pressure with repeatable event-to-event sound energy release. The choice of C-4 was preferable to the LSAAP demolition signal because of the flexibility in locating the C-4 charges, and it allowed better control over the source conditions. The LSAAP demolition signal was used on a target-of-opportunity basis to acquire measurements of the LSAAP demolition source signature for noise modeling. Because a small amount of C-4 was available on-site, transportation was not difficult. A plan to bring loudspeakers was abandoned because of the difficulty in transporting and powering them.

A C-4 source was placed at either end of the two short propagation paths to mimic reciprocal transmission (RT) along the linear microphone arrays. With RT comparisons, the average over any bias-type calibration errors could be recognized, by using diversified sources, microphones, and (of course) propagation direction at each comparison distance. The RT comparisons, if done over a short-enough time span, also held potential to estimate the variability due to only anisotropic wind effects. Refraction effects due to temperature stratification alone were expected to be isotropic for these RT paths.

To minimize acoustic shielding by topography, both RT paths were designed to follow a height contour segment, nearly straight, extending at one end across an open field in the demolition area, and at the other end through a stand of trees. The local slope transverse to the RT paths was small and eastward, approximately 1:80. A 10-m (33-ft) high dirt bunker was located approximately 60 m (197 ft) east of source location 2 (TC2). Figure 1 shows a layout of the experimental area.

To investigate angle-of-arrival at the RT centers, two additional microphones were provided there, minimally giving a 3-m (9.8-ft) vertical baseline and a 3-m (9.8-ft) horizontal baseline. Out of convenience, all of the microphones in each RT were attached to multichannel recorders. This provided an opportunity to estimate arrival times for signals propagating along either linear array, and some additional possibilities to use signal correlation to investigate side-on arrivals from backscattered

signals. The RT recorders were not synchronized, although it would have been possible, with time permitting, to add a common signal to an unused channel on both recorders.

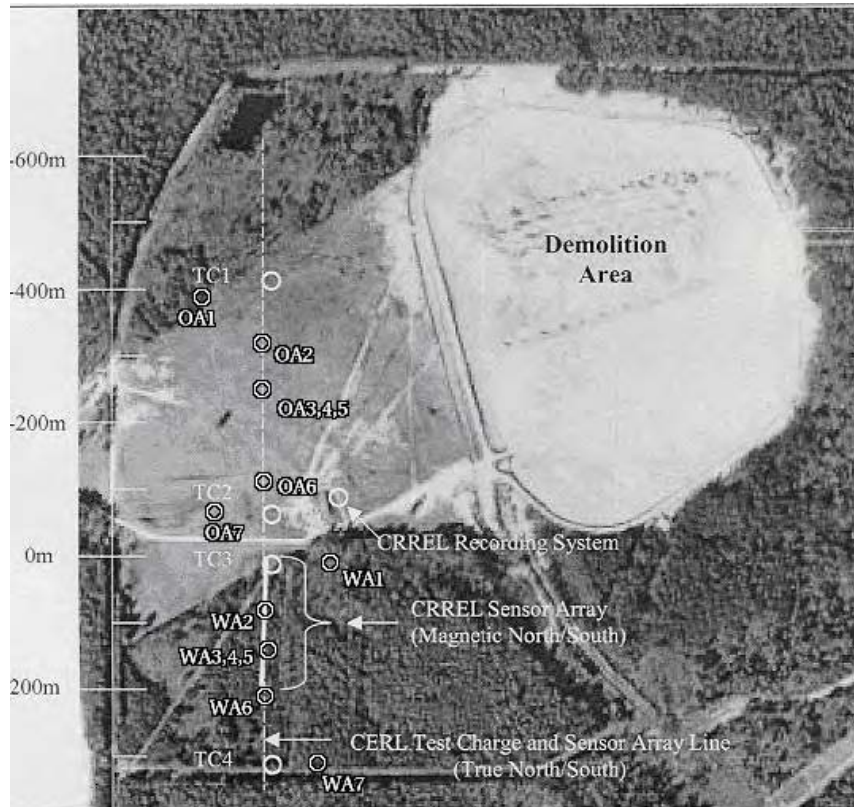


Figure 1. Experimental layout.

The TC numbers are source locations, WA numbers are microphone locations within the woods, OA numbers are microphone locations in the clearing. North is up. OA3, 4, 5 are nearly colocated, as are WA3, 4, 5. Credit to David Carbee for figure.

3 Blast Data Analysis

The data taken in July 2002 at LSAAP were analyzed in a variety of ways. Spectra from individual explosions with sensibly identical test configurations were compared. Next, the effects of charge size were examined. Then the data were grouped according to percentage of sound propagation path forested and by relative source and receiver locations. These methods of data analysis were performed both for peak levels and 1/3-octave band spectra. Comparisons were made with regard to actual measured level, scaled difference in levels between two measurement locations (transfer function method), and excess attenuation (EA). Excess attenuation is the amount of additional attenuation present beyond a theoretical prediction involving only spherical spreading and atmospheric absorption. Examples of analyzed data are given in the following sections. A summary of the results is included below; more detailed conclusions are given in each section.

Overall, some forest appeared to be better (provides more EA) than none. Additionally, no forest (open field) is slightly better than all forest for propagation distances of less than 340 m (1115 ft), and some forest also is better than all forest. Part of this effect might be due to the additional attenuation introduced when the acoustic wave impinges on a clearing-forest interface. At that point, some of the energy is backscattered, and some is transmitted. Acoustic propagation in the forest was much more stable than in the open clearing. Analysis of peak sound pressure levels have been marginally informative; the data are difficult to interpret due to larger variability within the sample sets than between them. The transfer function method of analysis also did not produce useful results.

It is important at this point to mention that some data were not recorded properly. Some data were electronically clipped, which means the microphone output voltage exceeded the input voltage range for the instrumentation recorders. Some microphones simply failed for a time, likely because of the high intensity of the sound waves due to blasts. These questionable and invalid data points were removed before analysis.

Identical Cases

The spectral data were grouped by identical test charge and location. Because these spectra were repeatedly obtained, averaging across individual explosions for identi-

cal cases probably would yield the best representation of the received spectra. The shot-to-shot variations were small. Figure 2 contains 1/3-octave band sound exposure spectra measured at positions in the open field (OA) and positions in the woods (WA) from a 5-lb charge of C-4, fired at location TC3 just outside the woods. Figure 3 contains 1/3-octave band sound exposure spectra measured at the same positions, but this time from a 1.25-lb charge of C-4 fired at location TC2 in the open field. There are several important things to notice about Figures 2 and 3. Spectra from individual explosions, graphed with other explosions that share the same test conditions (source location, charge size, receiver location) are remarkably similar, indicating that the test is repeatable. Looking carefully at the two sets of graphs, it is clear that propagation through the forest has a different effect on the 1/3-octave sound exposure level spectra than when the propagation path is largely within the open field. The forest data shows a distinctive “ground dip” in frequency at about 200 Hz. The existence of the ground dip in the spectrum indicates coherent, destructive interference of a direct sound path and a ground-reflected path. Its position in the spectrum depends on the source-receiver geometry and ground impedance. The ground dip is absent from most OA spectra, except for OA2. Absence of the ground dip in the open field likely indicates that the ground-reflected wave was either weak or absent at the receivers. Because the ground characteristics (porosity, density, etc.) are different in the open field and the forest, they have different ground impedances.

Charge Size

Charge size affects two major aspects of the blast signals: frequency spectrum and peak sound pressure level. An increase in charge weight implies a compression of the spectrum shape toward lower frequencies. The spectrum is assumed to be shifted in both level and center frequency. In this data set, the center frequency is expected to shift two 1/3-octave bands lower in frequency and the peak sound pressure level is expected to increase by 4 dB. The spectrum did indeed shift as expected, but the level change was not as anticipated. Instead, the peak level difference was approximately 6 dB. The level difference in the spectra was 4 dB for the center frequency, negligible for lower frequencies, and 6-10 dB for higher frequencies (Figure 4).

It is interesting to note that artificially shifting the 1.25-lb spectrum two 1/3-octave band bins lower in frequency will cause the spectral peaks to line up. See, for example, Figure 5. If the propagation is over only an open field, the match is good, merely offset in level. If there is propagation through any amount of forest, the ground impedance frequency dip is present. This dip is independent of charge size, because it is a function of the propagation environment and geometry. Therefore,

when there is some forested propagation, spectral data from different charge sizes cannot be averaged.

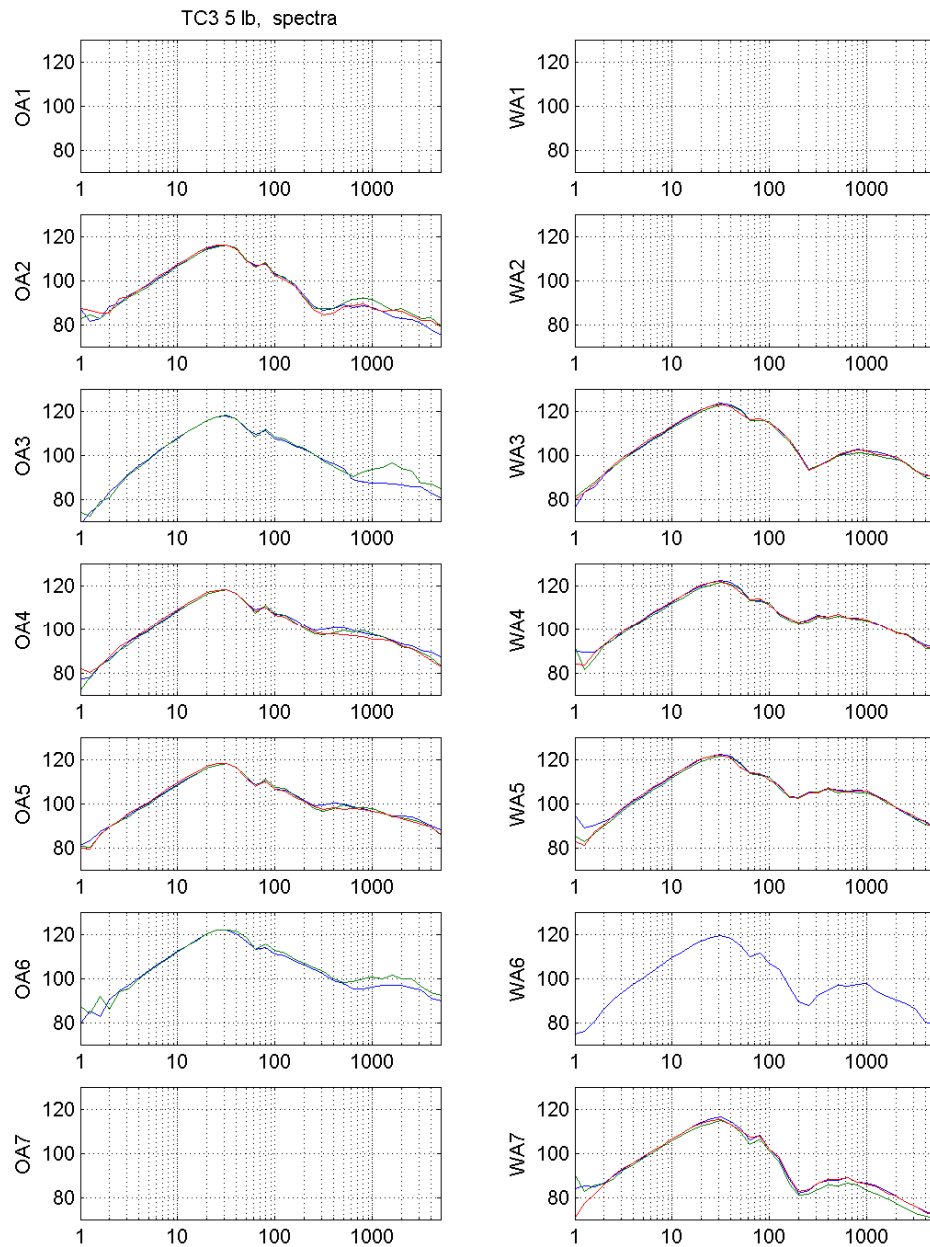


Figure 2. Spectra of repeated explosions of 5-lb charges of C-4 from source location TC3. The y-axis is measured 1/3-octave band sound exposure level (dB); the x-axis is frequency (Hz).

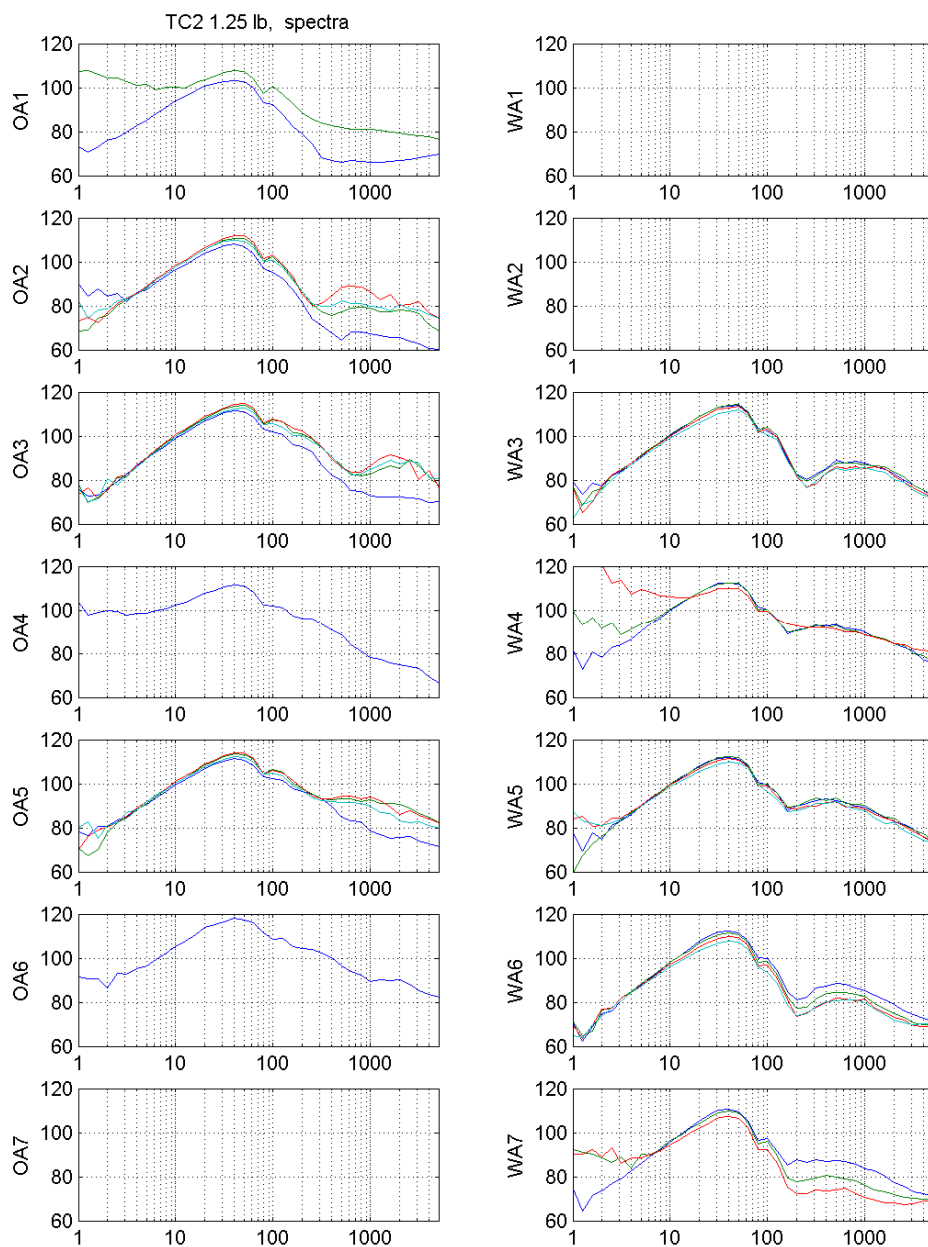


Figure 3. Spectra of repeated explosions of 1.25-lb charges of C-4 from source location TC2. The y-axis is measured 1/3-octave band sound exposure level (dB); the x-axis is frequency(Hz).

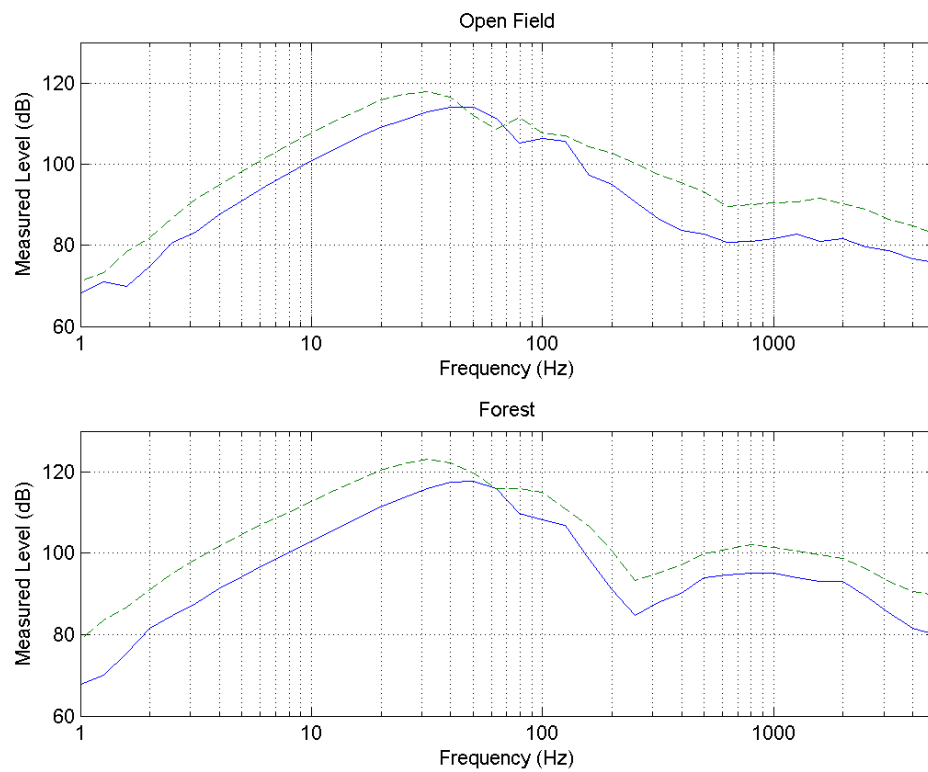


Figure 4. Spectral variations with charge size.

Top graph is source TC1, receiver OA3 (open clearing). Bottom graph is source TC2, receiver WA3 (forest). In both, the solid line is 1.25-lb C-4 and the dashed line is 5-lb C-4. The y-axis is 1/3-octave band sound exposure level (dB).

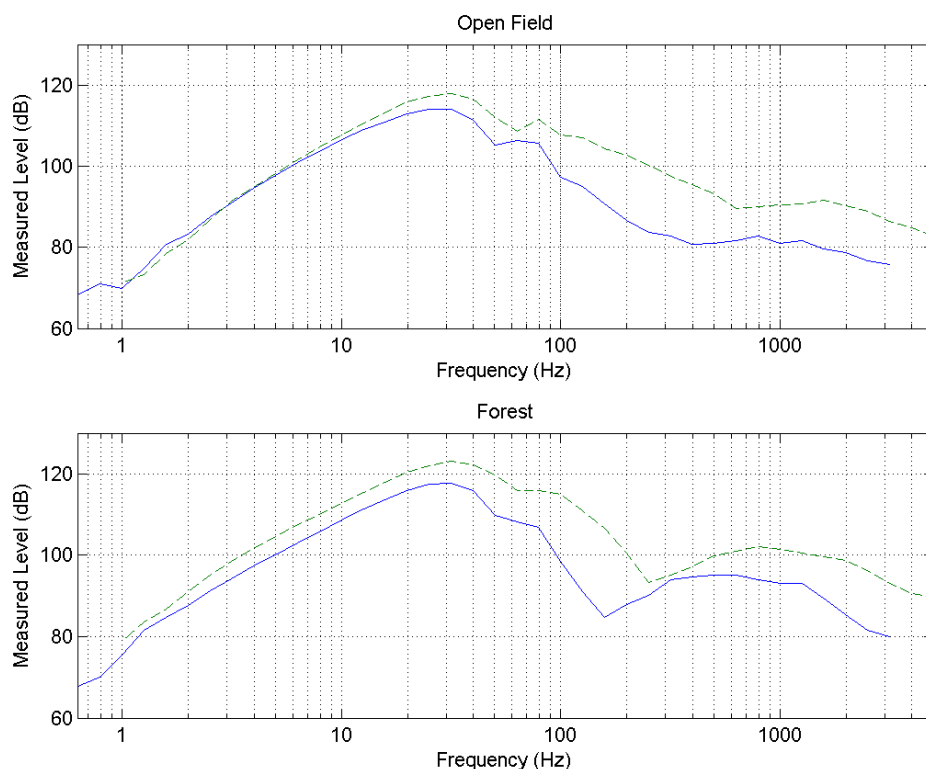


Figure 5. Spectral variations with charge size.

Top graph is source TC1, receiver OA3 (open clearing). Bottom graph is source TC2, receiver WA3 (forest). In both, the solid line is 1.25-lb C-4 (but artificially shifted two 1/3-octave band frequency bins lower than actually measured). The dashed line is 5-lb C-4 (as measured). The y-axis is 1/3-octave band sound exposure level (dB).

The charges used in the experiment were 1.25-lb and 5-lb C-4. Data also was taken from actual demolitions so those spectra could be compared to the C-4 spectra. Demolition spectra are shown in Figure 6. The demolition spectra have similar characteristics to the C-4 above 15 Hz. Below 15 Hz the demolitions have significant energy content down to 1 Hz, unlike the C-4.

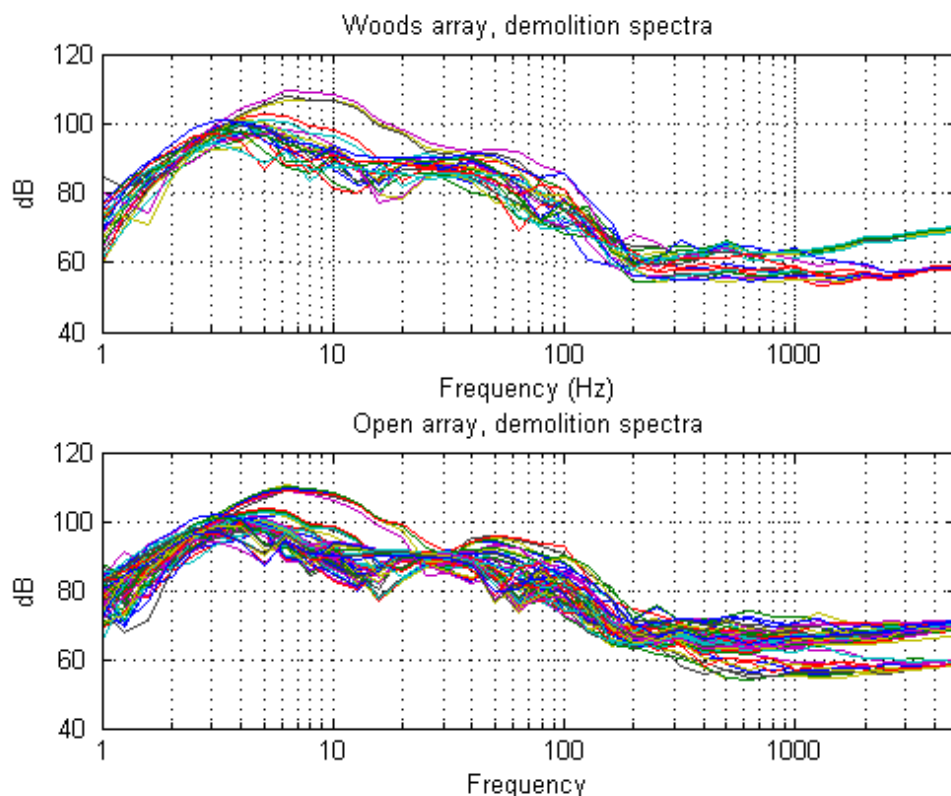


Figure 6. Measured spectra of LSAAP demolitions.
The y-axis is 1/3-octave band sound exposure level (dB).

Path Dependence

The attenuation of the experimental blast waves is highly dependent on the path the acoustic wave traveled. Any amount of propagation through trees introduces the ground dip in the spectra. Figure 7 shows EA of peak sound pressure levels, divided into percentage of propagation path forested. It can be concluded that, if all other parameters are kept equal, some forest is beneficial for noise mitigation compared to open grassland, but a fully forested path is no better than a clearing for noise mitigation when compared to open grassland. It also can be said that placing the source in the open and propagating into a forest causes more attenuation of the peak sound pressure level than placing the source inside the forest and propagating into the open. In this case, the benefit ranges from 1 to 4 dB in peak level. Figure 8 is a representation of peak sound pressure level vs. distance. The solid lines are predictions using ANSI S2.20 (American National Standards Institute S2.20 1983). The experimental data followed the ANSI curves fairly closely. There appears to be a “crossover point” in which the levels in the forest decrease more rapidly than in the open field. This occurs near 340 m (1,115 ft), which is the maximum distance propagated through a homogeneous medium in this experiment. This means that

the acoustic field has definitely passed through the forest/field boundary. It also is interesting to note that received levels in the forest trend away from the ANSI prediction, and the received levels in the open field trend toward the ANSI prediction. Figure 9 illustrates this by graphing the difference between the data points and the ANSI prediction, then doing a linear fit to the results to better identify the trend. Both methods of analyzing the data reinforce the conclusion that some forest is better than none, and a source in the open field is more beneficial than one in a forest.

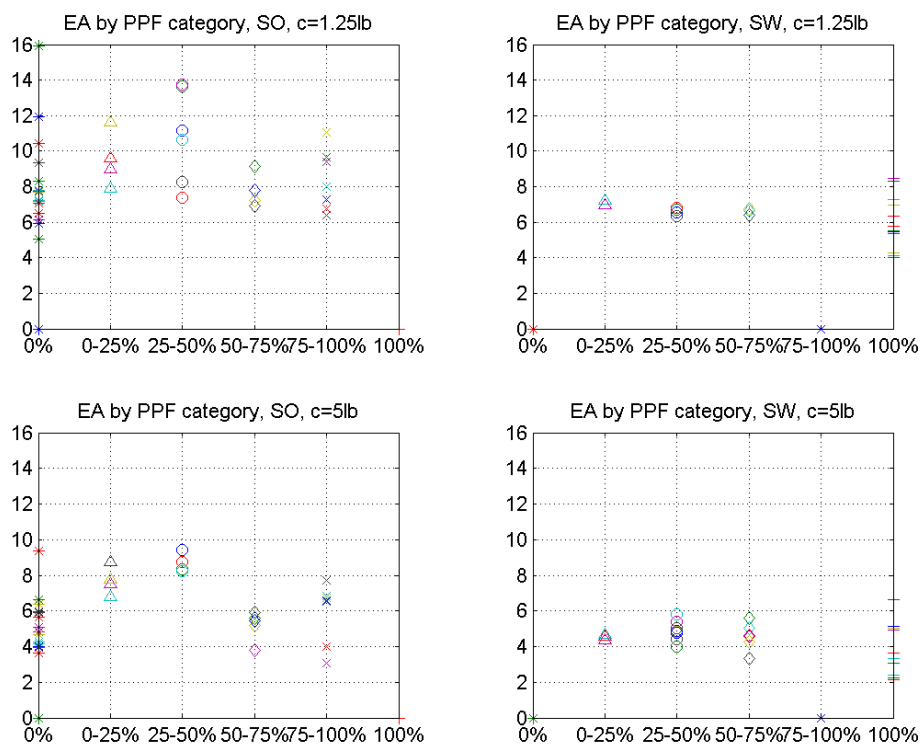


Figure 7. Peak sound pressure levels, divided into percent path forested categories. EA is excess attenuation. PPF is percentage propagation path forested.

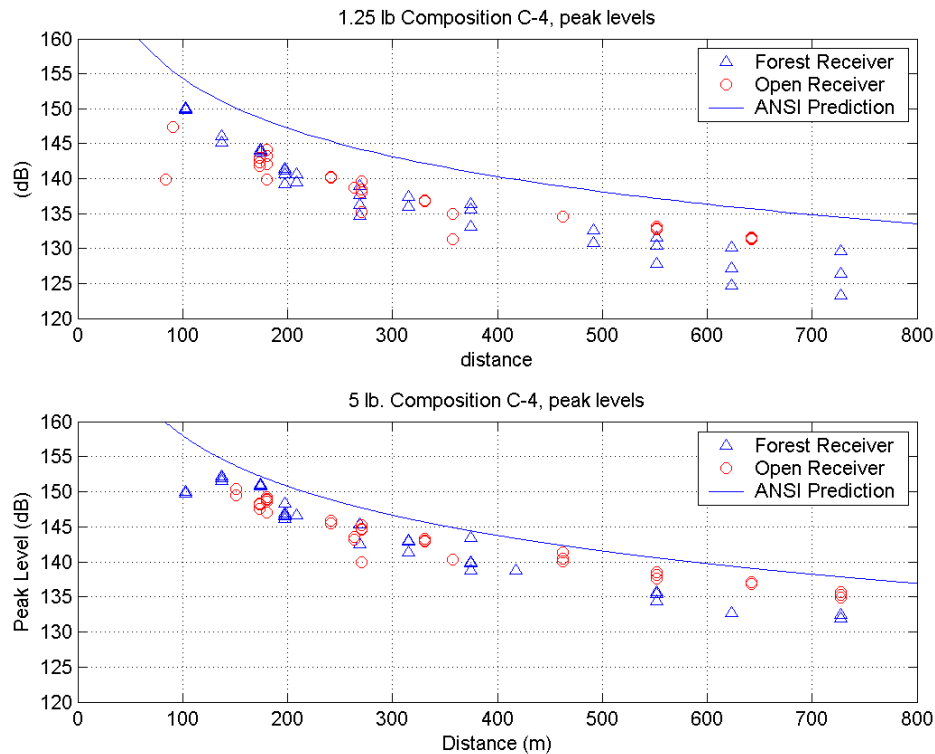


Figure 8. Measured peak sound pressure level vs. distance.
 Top graph charge is 1.25-lb C-4. Bottom graph charge is 5-lb C-4. The solid line is the prediction using ANSI S2.20 for respective charge size. In both graphs, circles are open receivers, triangles are forest receivers.

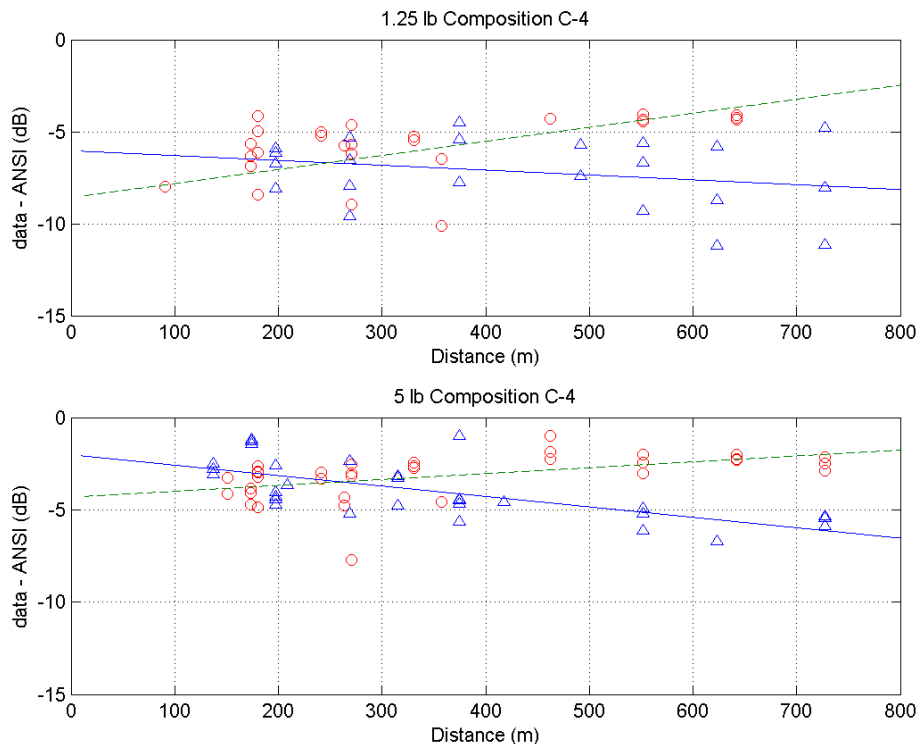


Figure 9. Difference between received levels and ANSI S2.20 predictions.
 Triangles represent receivers in the forest, circles represent receivers in the open field. The dashed line is a linear fit to the open field data, and the solid line is the linear fit to the forest data.

4 Modeling Efforts

The sound attenuation in a forest was estimated by developing a computer model based on atmosphere, forest, and ground properties. The modeling was approached in two stages. The first stage consisted of a simple point-to-point propagation model. This model was made up of several parts: an acoustic source model (the Friedlander model), atmospheric absorption of acoustic energy, spherical spreading of the acoustic wave, attenuation due to scattering from tree trunks, and effects of the ground. The entire medium for this model is assumed homogeneous. This means that trunks and branches fill all space, and the atmosphere is nonrefracting. The benefit of this method was in determining the appropriate parameters for the ground and determining the appropriateness of the Friedlander model (Friedlander 1946) as the acoustic source model. As can be seen in Figure 10, the agreement is quite good, with the exception of the magnitude of the most energetic frequency band and the magnitude of the ground dip. However, over the relatively short propagation distance (174 m [571 ft]), little atmospheric effect is expected. To create a more accurate physical representation of the forest, to incorporate atmospheric effects, and to allow for long-range propagation, a different modeling approach was needed. The second stage of model development consisted of the parabolic equation (PE). This model incorporates a height-dependent sound speed profile in the propagation, which allows one to consider the effects of refraction due to temperature and wind variations. It also is possible to insert finite-thickness absorbing horizontal layers to simulate attenuation caused by scattering and allowing sound to propagate freely above the forest canopy. Figure 11 is a representation of the geometry. For a detailed description of the PE model, see Swearingen and White (2004).

Predictive Results

Does the presence of a forest around a noise source actually help to mitigate noise? One way to extract this information from the model is to compare open field predictions to forest predictions. These predictions assume a homogeneous propagation medium, i.e., there is only forest or only open field, no interfaces. Figure 12 shows the difference in level between open field and forest predictions at both short (174 m [571 ft]) and long (1400 m [4,593 ft]) ranges. If the resulting difference is positive, the open field attenuates less noise over that frequency range. If the resulting difference is negative, the forest attenuates less noise over that frequency range. It is important to note that the model does not include atmospheric turbulence. Omit-

ting atmospheric turbulence causes the open field propagation upwind to develop a strong shadow zone that would be somewhat lessened in a real setting (Daigle et al. 1986).

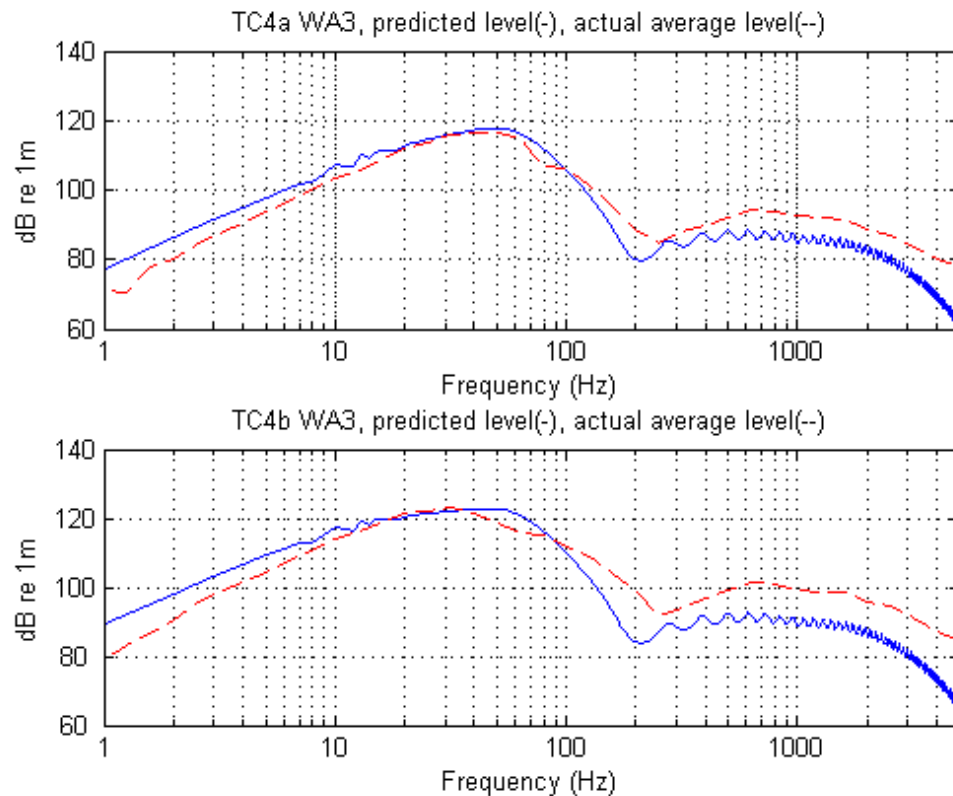


Figure 10. Comparison of predicted spectrum to measured spectrum, point-to-point model. The y-axis is narrow-band sound exposure (dB).

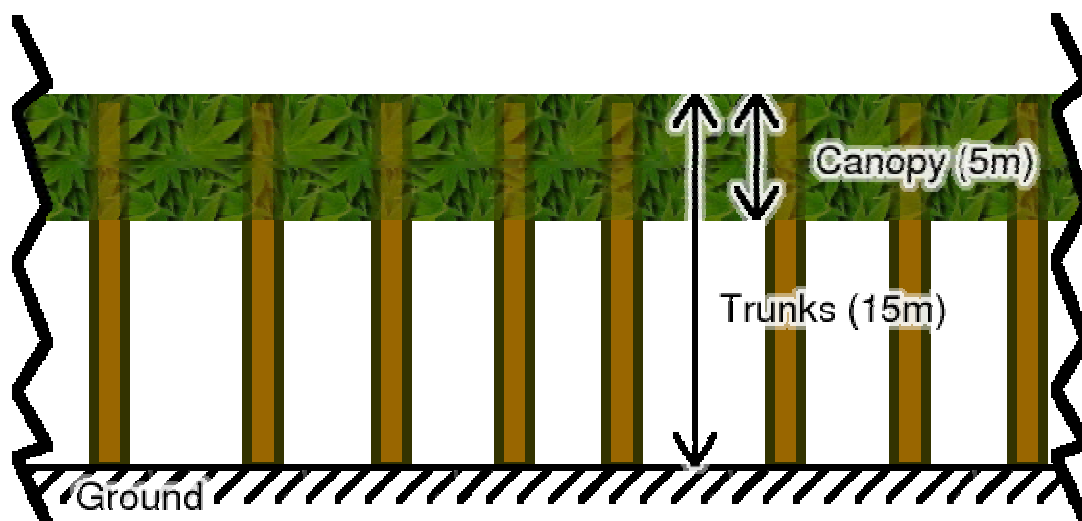


Figure 11. Geometry of the forest Green's Function Parabolic Equation (GFPE) model. Canopy is modeled using parallel cylinders of two different sizes.

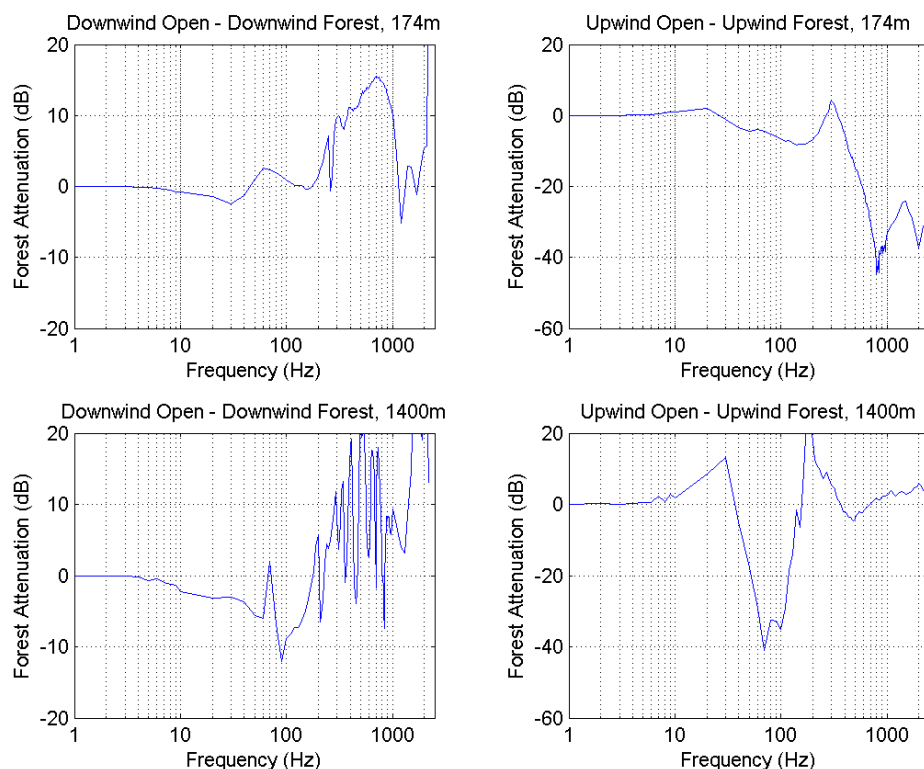


Figure 12. Relative attenuation of forest vs. open field.

A positive value indicates more attenuation in the forest. A negative value indicates more attenuation in the open field.

Several conclusions can be drawn from the comparison graphs in Figure 12. In the short-range (174 m [571 ft]), downwind case, the forest is beneficial above 200 Hz, by an average of 8 dB. Between 45 and 100 Hz, there is a slight benefit (1 to 2 dB) from the forest. Below 45 Hz, the forest provides less attenuation than the open field. In the short-range (174 m [571 ft]), upwind case, with the exceptions of 20 Hz and 300 Hz, the open field is more beneficial in terms of noise mitigation. In the long-range (1400 m [4,593 ft]), downwind case, the forest is beneficial for mitigation above 200 Hz, on the order of 8 to 10 dB on average, and anywhere from 0 to 20 dB. Variations are a result of the frequency dependences associated with each element in the model and their interactions. Below 200 Hz at long-range downwind, the open field causes 3 to 11 dB more attenuation than the forest. In the upwind case, the forest is more beneficial for mitigation below 35 Hz, significantly worse between 35 and 150 Hz, and then nominally more attenuating than the open field above 150 Hz.

Comparisons

The final comparison was made between a prediction containing the actual arrangement of trees at LSAAP and one with half of the trees harvested by thinning. The comparisons are given in Figure 13. The most obvious effect here is that the thinned forest provides 3 to 10 dB less attenuation above 200 Hz at 1400 m (4,593 ft). Insignificant change was noted at the 174 m (570.8 ft) distance. It is important to note that no changes were made in the microclimate model to account for the thinner tree stand density. A less dense forest, and likewise a less dense canopy cover, should exhibit different microclimate effects than the original conditions (Tunick 2003). If the microclimate is indeed the most significant factor below 200 Hz, the comparison does not shed much light on the low-frequency properties of the thinned forest.

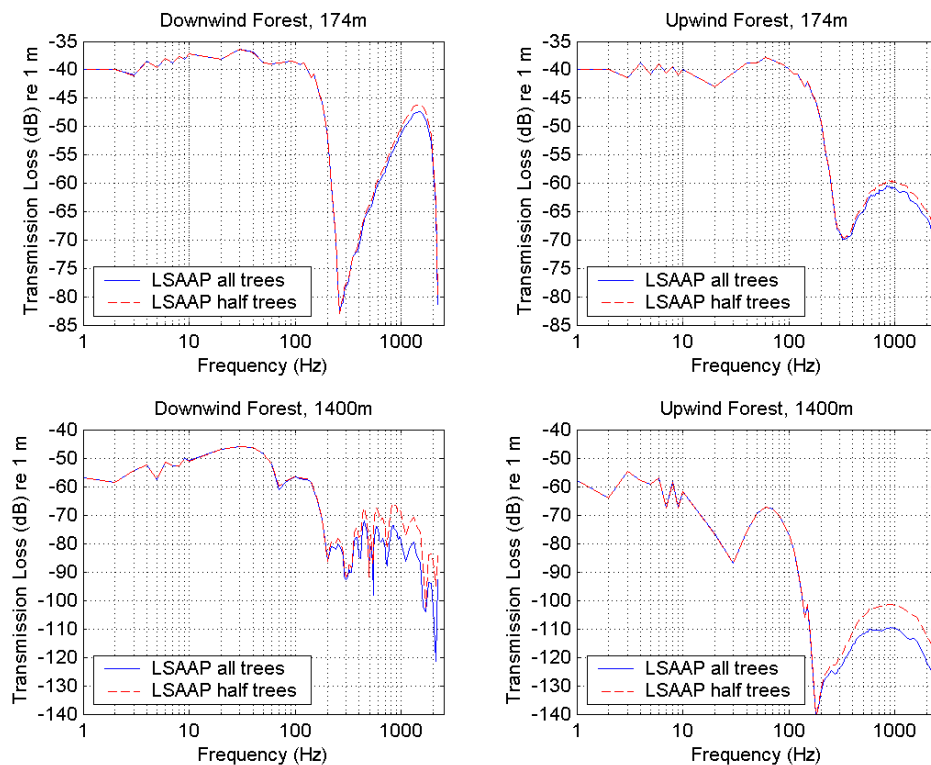


Figure 13. GFPE predictions.

Comparison between original setup and half of the trees thinned. Only the number of trees was modified.

5 Conclusions and Recommendations

Conclusions

This study showed that forests do indeed provide some noise mitigation benefit. This can be as much as 4 dB unweighted peak, if the propagation path is partially forested. To realize the greatest noise mitigation benefit, the source must be located in the open field and the receiver in the forest. However, when examining experimental frequency spectra, it is unclear if there is a greater benefit caused by the forest for low frequencies, or if the peak level reduction is mainly due to significant reductions in higher frequencies. Because the simulations only accounted for changes in the density of the trees, the results from the comparison between full LSAAP forest and those with one-half as many trees showed changes only above 200 Hz. Lower frequencies were largely governed by atmospheric effects, which are expected to change as a function of tree number density and corresponding canopy density. The atmospheric profile chosen for the simulations was adapted from a published paper (Heimann 2003). Unfortunately, at this time the profile cannot be altered to reliably take into account changes in canopy. Therefore, the low-frequency contribution of the forest is not fully understood, and alterations to the forest and the corresponding effects on the microclimate also are not understood. The study did not prove conclusively if thinning trees at LSAAP will have an effect on the low-frequency noise levels.

Recommendations for Future Work

Several important aspects of the forest have yet to be studied in detail. First and foremost, a better understanding of the microclimate in and above the forest, and its influence on sound propagation both within and above the forest, is needed. Second, the effects of a forest edge on sound propagation needs to be understood. Potentially this could lead to the use of fire brakes as a noise mitigation technique. Third, information on forest effects over longer distances is needed. Fourth, a better understanding of the impacts of forest management techniques, such as thinning or burning, on the acoustic properties of the forest is needed. This could lead to recommendations on forest management for noise mitigation.

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REPORT DOCUMENTATION PAGE				<i>Form Approved</i> OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 10-2005		2. REPORT TYPE Final		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Effects of Forest on Blast Noise				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Michelle E. Swearingen and Michael J. White				5d. PROJECT NUMBER MIPR	
				5e. TASK NUMBER H1LH7C	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) PO Box 9005 Champaign, IL 61826-9005				8. PERFORMING ORGANIZATION REPORT NUMBER ERDC/CERL TR-05-29	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Environmental Center 5179 Hoadley Road Aberdeen Proving Ground, MD 21010-5401				10. SPONSOR/MONITOR'S ACRONYM(S) SFIM-AEC-TSR	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.					
14. ABSTRACT Low-frequency impulsive noise, characteristic of demolitions, artillery, and armor, is difficult to mitigate. In 2001, ERDC-CERL researchers were tasked to study the potential attenuation caused by a forest. After a thorough review of published work, it was determined that an experiment was necessary. This took place in July 2002 at the Lone Star Army Ammunition Plant in Texarkana, Texas. This report presents the data analysis and draws conclusions about the effectiveness of a forest stand on noise mitigation. Additionally, some predictive modeling has been performed, and those results also are included.					
15. SUBJECT TERMS noise simulation modeling range management forests					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 30	19a. NAME OF RESPONSIBLE PERSON Michelle E. Swearingen
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code) (217) 352-6511 ext 4521